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THE START-UP OF A GAS TURBINE ENGINE USING COMPRESSED AIR TANGENTIALLY FED ONTO THE BLADES OF THE BASIC TURBINE

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16. Abstract

To increase the reliability and motor lifetime of a gas turbine engine, the authors suggest using compressed air. The authors carried out experiments, and the results are shown in the form of the variation in circumferential force as a function of the entry angle of the working jet onto the turbine blade. The described start-up method is recommended for use with massive rotors.

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The Start-Up of a Gas Turbine Engine Using Compressed Air Tangentially Fed Onto the Blades of the Basic Turbine

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The enhanced reliability and increased motor lifetime of /135* a gas turbine engine place elevated demands on its servicing systems, including the start-up system.

One of the ways of raising the reliability of the starter layout under conditions of lengthy operation is the use of a starting system without starter. Such a system provides for the feeding of compressed air directly onto the turbine blades across special starting nozzles, tangentially arranged about the perimeter of the turbine housing.

Fig. 1 shows a schematic drawing of the mutual arrangement of the peripheral section of the working blade and the starting nozzle.

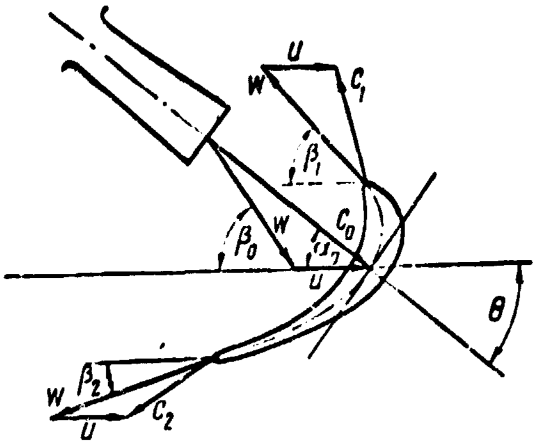

Fig. 1. Diagram of the arrangement of the starting nozzle and working blade.

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It is known [1] that the sum of the forces acting on the system can be found from the theorem of change in momentum of the flow:

$$P = G_0 c_0 - G_1 c_1 - G_2 c_2,$$

where G_0, G_1, G_2 is the mass rate of flow of the working substance per unit of time; c_0, c_1, c_2 are the velocities of the working substance in the system at the inlet and outlet. The circumferential force is:

$$P_u = G_0 c_{u0} - G_1 c_{u1} - G_2 c_{u2}.$$

Let us suppose that the current is laminar, the relative velocities of the flow at the inlet and outlet from the blades are identical, and the losses are provided for by a factor ξ, which is experimentally determined.

The amount of working substance spreading over the blade toward the inlet G_1 and outlet G_2 edges will be, respectively:

$$G_1 = \frac{G_0}{2}\left[1 + \sin\left(\Theta - \operatorname{arctg}\frac{\sin\alpha_0}{\cos\alpha_0 - \frac{u}{c_0}}\right)\right];$$

$$G_2 = \frac{G_0}{2}\left[1 - \sin\left(\Theta - \operatorname{arctg}\frac{\sin\alpha_0}{\cos\alpha_0 - \frac{u}{c_0}}\right)\right].$$

In view of the assumptions, the circumferential force is:

$$P_u = \xi\,[G_0\,(c_0\cos\alpha_0 - u) + G_1\,(w\cos\beta_1 - u) + G_2\,(w\cos\beta_2 - u)].$$

After substituting the values for G_1 and G_2 we obtain:

$$P_u = \xi G_0 \left\{ (c_0 \cos \alpha_0 - u) + \frac{1}{2} \sqrt{c_0^2 + u^2 - 2 c_0 u \cos \alpha_0} \left[\cos \beta_1 + \cos \beta_2 + (\cos \beta_1 - \cos \beta_2) \sin \left(\Theta - \operatorname{arctg} \frac{\sin \alpha_0}{\cos \alpha_0 - \frac{u}{c_0}} \right) \right] \right\}.$$

As shown by research, a change in the angle α_0 within limits of 0 to 30° has little effect on the size of the circumferential force P_u, which is a maximum in this range of angles. /136

In order to determine the loss factor ξ, an experiment was set up at the turbine stage with middle rotor diameter 0.6 m, height 0.1 m, pitch 0.03 m, and blade turn angle Θ = 45°; the exit angles at the edges were β_1 = 90° and β_2 = 25°.

A possibility was provided for changing the angle α_0 in the equatorial plane (U-Z) and the angle γ in the meridional plane (R-Z).

The quantity of working substance and the rate of flow were changed by varying the parameters of the working substance and the geometrical dimensions of the nozzles.

In the experiments the pressure was maintained within limits of 5.88 bar, the angle α_0 varied from 0 to 45°, the angle γ from 25 to 80°. The circumferential force was measured by a dynamometer. The magnitude of the force from the jet of working substance was measured with the blades in various positions with respect to pitch (with a one degree turn), and then averaged by a graph analytical method.

The results of the experiments are shown in Fig. 2 in the form of the variation in circumferential force as a function of the entry angle of the working jet onto the turbine blade α_0

when the angle γ is equal to 40°. The loss factor ξ, according to the experimental findings, was 0.6-0.62.

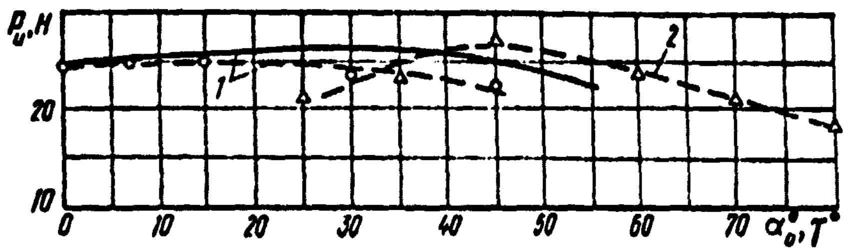

Fig. 2. The circumferential force as a function of the nozzle angles of position: 1 - as a function of angle α_0; 2 - as a function of angle γ; solid line - calculated curve; broken line - experimental.

The influence of the angle γ is extreme and, as shown by the experiments, we may consider γ = 40-45° as most rational; the given values of ξ also correspond to this value.

After computing P_0, we can determine the torque $M_t = P_u r$, where r is the outer radius of the rotor, and then we can also determine the power of the starting layout:

$$N = M_t \omega.$$

For the investigated case, the specific rate of flow of compressed air when the pressure of the air in front of the nozzle is P_p = 9.8 bar and the circumferential velocity varies between 0 and 70 m/s is:

$$\bar{G}_p = \frac{G_n}{P_u} = 0{,}00285 \div 0{,}0033 \quad \text{kg/N·s}.$$

The specific rate of flow of compressed air, adjusted per unit of power, under the same air parameters in front of the nozzle and when u = 70 m/s, is: /137

$$\bar{G}_N = \frac{G_n}{N} = 0{,}0493 \quad \text{kg/s·kW}.$$

When a small-scale turbine is used as a starter motor, the rate of flow of working substance will be less, but a rigid mechanical linkage is required with the rotor of the turbo-compressor being started, the reducer, and the uncoupling clutch.

As shown by investigations, for purposes of economizing on working substance when starting up the gas turbine engine of a small-scale turbine, the start must be done quickly, for despite the increasing rate of flow per second the overall amount of air for the start-up is diminished [2]. For example, for an GTM having a rotor moment of inertia $J = 50\ kgm^2$, when the rate of flow of air per second is $G_0 = 0.5$ kg/s the start-up is done in 122 seconds, while the overall rate of flow of air is equal to 62 kg; when the rate of flow per second is increased to 5 kg/s, the rotor attains its starting revolutions ($u = 70$ m/s) in 10 seconds, and the overall rate of flow of air is reduced to 50 kg.

An analysis of the start-up without starter reveals that the consumption of air does not depend on the starting time (for a rotor similar to that in the preceding example, the necessary air consumption is 88 kg for any given start-up time).

This peculiarity of the described start-up method recommends it for use with massive rotors, requiring a lengthy time of acceleration for warm-up, and in this case it is fully competitive with a small-scale turbine.

A non-rigid gas dynamic transmission with start-up rotor minimizes the possibility of fracture resulting from incorrect action on the components of the starting system.

Moreover, large rates of flow of compressed air per start allow us to recommend the described start-up as the main operation only when a capacious source of compressed air is present

(a powerful multipurpose compressed air system, tapping of air from the compressor of a neighboring gas turbine engine in operation, etc.).

When it is necessary to create a back-up starting system for the GTE from an energy source other than the main, e.g. an electric source, we may recommend a similar start-up from cylinders of compressed air or a compressor of sufficient power.

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